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The Interaction among the Regulation of New Plant Breeding Techniques, GMO Labeling, and Coexistence and Segregation Costs: The Case of Rapeseed in the EU

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Abstract

We analyze the market and welfare effects of regulating crops derived by New Plant Breeding Techniques (NPBTs) as genetically modified (GM) or conventional products. We consider the EU mandatory scheme for labeling GM products and a voluntary non-GM scheme for labeling livestock products derived from non-GM feed. We develop a partial equilbrium model that explicitly takes into account both the coexistence costs at farm-level and the segregation and identity preservation costs at downstream level. By applying the model to EU rapeseed, we find that regulating NPBTs as GM (as compared to non-GM) in combination with mandatory and voluntary labeling increases prices and makes consumers overall worse off and producers better off. We also show that higher coexistence costs make the price increasing effect even stronger. Voluntary non-GM labeling applied to feed makes consumers in this sector overall worse off but benefits farmers and rapeseed oil consumers overall as long as segregation costs are low. Consumers of biodiesel and industrial products such as lubricants produced from GM rapeseed benefit from high segregation costs. We show that the effects of farm-level coexistence costs largely differ from the effects of downstream market segregation costs.

JEL: Q18

Keywords: New Plant Breeding Techniques, GMO, labeling, coexistence, identity preservation, regulation, vertical product differentiation.

Introduction

Since the adoption of the official definition of genetically modified organisms (GMOs) in the European Union in 1990, a number of new techniques have been developed to genetically modify plants.[1] Currently regulators in different countries, including the European Union and the United States, assess whether these biotechnology-driven “New Plant Breeding Techniques” (NPBTs) should fall within the scope of the GMO regulation (Lusser and Davies 2013).[2] Because plants derived by NPBTs do not necessarily contain an inserted transgene, they are often indistinguishable from crops derived through conventional breeding (Lusser et al. 2011). Therefore, one of the main questions in determining how NPBTs should be regulated in the European Union is whether the technique itself or the organism produced by such a technique must be regulated by the current GMO legislation (Hartung and Schiemann 2014). A similar debate may arise in the United States in the context of labeling food products.

The decision whether crops derived by NPBTs are classified as GM or as non-GM has important economic implications for the product registration, research and development, trade, cultivation, and marketing of NPBTs. The registration costs are low for non-GM crops while the cost of the approval procedure for GMOs in the European Union ranges between 7-15 million

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[1] The Directive 2001/18/EC on the deliberate release into the environment of GMOs defines GMOs as an “organism, with the exception of human beings, in which the genetic material has been altered in a way that does not occur naturally by mating and/or natural recombination” (European Commission 2001).

[2] In 2007, the EU Commission and different National Component Authorities named eight NPBTs for which the regulation is unclear: zinc finger nuclease (ZFN) technology; oligonucleotide-directed mutagenesis; cisgenesis and intragenesis; RNA-dependent DNA methylation; grafting on GM rootstock; reverse breeding; agro-infiltration; and synthetic genomics (Hartung and Schiemann 2014).

euros and is very time-consuming (Kalaitzandonakes et al. 2007, McDougall 2011, Tait and Barker 2011, Smart et al. 2016). High approval costs may disincentivize firms to invest in the innovation of NPBTs. Furthermore, if an NPBT-derived crop is considered a GMO in one country but not in another, asynchronous approval and low-level presence can lead to trade disruptions (Stein and Rodríguez-Cerezo 2010). GM products must be labeled as such, and if GM and non-GM products are marketed side-by-side, segregation and identity preservation of the non-GM product are required (European Commission 2003a, b).

In this article, we analyze the market and welfare effects of alternative NPBT regulations and focus on herbicide-resistant rapeseed to study these effects. There are at least three reasons why we focus on rapeseed. First, rapeseed accounts for more than 50 percent of both total supply and use of oilseeds in the European Union (European Commission 2016). Second, in a survey conducted by the Joint Research Center of the European Commission, plant breeding companies identified the herbicide-resistant rapeseed as one of the first potential commercial products derived by NPBTs (Lusser et al. 2011).[3] Third, rapeseed oil and its joint product meal are used in the food supply chain as food (e.g., cooking oil) and feed (e.g., protein source in compound feed for cattle, pigs, and poultry) as well as in the industrial supply chain, for example, as a feedstock for lubricants and biodiesel. Whereas GM labeling applies to food and feed products, it usually does not apply to industrial products. Hence, the segmentation of markets implies that the regulation and labeling do not affect all consumers and producers equally.

[3] In their survey of plant breeding companies, Lusser et al. (2011) identify the following products as likely to be among the first commercial products derived from NPBTs: herbicide- resistant rapeseed and maize; fungal-resistant potatoes; drought-tolerant maize; and scab-resistant apples and potatoes with reduced amylose content.

We look at how different labeling schemes affect the welfare of different market agents. In addition, we analyze the effects of farm-level coexistence and processing/marketing segregation and identity preservation costs. We show that regulating NPBT-derived crops as GMOs in combination with the GMO labeling regulation increases market prices, decreases consumer welfare but increases producer welfare relative to regulating NPBT as non-GM. We also show, that higher coexistence costs make the price increasing effect even stronger. When coexistence costs are high enough, no NPBTs are used. Downstream market segregation costs affect the market differently than do coexistence costs by increasing the price of non-GM oil and meal but reducing the price of non-GM rapeseed.

We find that voluntary non-GM labeling, whereby producers can label livestock products derived from non-GM meal, benefits all farmers and oil consumers but makes meal consumers overall worse off (as compared to a situation where the voluntary labeling is not allowed). If, however, segregation costs are high, only industrial and biodiesel consumer gain from voluntary non-GM labeling.

Background: Labeling and Coexistence

The discussion of regulating NPBTs brings back much of the debate of the last two decades on the economic effects of introducing GMOs in general and GM labeling and coexistence in particular. Labeling in the European Union is mandatory for food and feed that contains GMOs (e.g., oil derived from GM rapeseed). However, the mandatory labeling scheme does not require to label livestock products derived from animals fed by GM feed (e.g., fed by GM rapeseed meal), although a voluntary labeling scheme for those products has emerged.

In the case of rapeseed, the mandatory labeling scheme affects only the oil market directly, whereas the voluntary non-GM labeling scheme affects only the meal market directly. In particular, oil can be used as food or converted into biodiesel and other industrial goods. The food, and hence the oil for human consumption must be labeled if it is derived from GM crops but industrial products do not require labeling. Retailers in Europe removed or announced to remove all GM products already in 1998, shortly after the first commercial cultivation of GM crops (Kalaitzandonakes and Bijman 2003). This exclusion of GM-labeled products has been adopted by almost all EU retailers and food manufacturers and is still in place today. Therefore, human consumption of oil is covered by non-GM oil whereas both GM and non-GM oils can be used industrially.

Rapeseed meal, the joint product of oil production, is mainly used as protein feed for milk, egg, and meat production. If firms want to offer products derived from non-GM feed, they have to comply with a voluntary non-GM labeling standard.[4] Some countries (e.g., Austria, Germany, and France) have implemented national non-GM labeling standards that vary in their requirements across countries (European Commission 2015). In Germany, for example, all major retail chains have started to offer or have announced to offer some of their retail brand livestock products (e.g., dairy products and eggs) with a non-GM label. Other voluntary labeling schemes, for example, in the Netherlands allow non-GM labeling only under highly restrictive circumstances, and the schemes in Belgium and Sweden prohibit non-GM labeling altogether (European Commission 2015).

Retailers' and industries' removal of GM food products has led to the absence of mandatorily labeled GM food oil whereas the voluntary labeling scheme has led to product differentiation of meal-derived products. Providing non-GM oil and meal in the presence of GM

[4] The non-GM labeling standard considers feed without a mandatory GM label as non-GM feed. Most non-GM labeling standards tolerate some adventitious (i.e., unintended or technically unavoidable) presence of GMOs. Most standards also define some time before slaughtering, milking, or laying eggs in which GM feed is tolerated.

cultivation requires GM and non-GM supply chains to coexist. Coexistence at farm-level mainly concerns the avoidance of potential economic losses that non-GM farmers can face, for example, through admixture due to cross-pollination if above a 0.9-percent threshold of adventitious (i.e., accidental or technically unavoidable) presence and if there exists a separate market for GM and non-GM products. To ensure coexistence, several EU Member States have implemented coexistence measures (see Beckmann et al. 2014 for an overview of coexistence measures in different EU Member States).[5]

In the European Union, GM farmers have to implement the coexistence measures and bear the costs of implementation (i.e., coexistence costs). These coexistence measures often result in costs that are greater than the benefits of GM cultivation, potentially preventing some farmers from adopting GM crops (Venus et al. 2016). Moschini (2015) shows that putting the burden of mandatory minimum distance requirements to achieve coexistence at farm-level entirely on GM producers, creates a bias against GM crop adoption, and to restore the efficient allocation, coexistence costs must be shared equally between adjacent GM and non-GM farmers. Moschini (2015) does not, however, consider the effects of segregation and identity preservation costs (henceforth segregation costs) on downstream markets explicitly.

The downstream market participants, such as agricultural traders, grain processors, and food producers, have to avoid commingling of GM and non-GM commodities if they want to preserve the non-GM identity. Therefore, in the downstream market, the non-GM firms are usually assumed to bear the direct costs of segregation and identity preservation (Mayer and Furtan 1999, Saak and Hennessy 2002, Fulton and Giannakas 2004, Lapan and Moschini 2004, Lence and Hayes 2005, Moschini et al. 2005, Sobolevsky et al. 2005, Lapan and Moschini

[5] Following the subsidiarity-based approach to coexistence, each EU Member State shall specify national measures.

2007).[6] For example, dairy companies that voluntarily offer non-GM labeled products must ensure through contracting, testing, documentation, third-party auditing, and certification that farmers feed only non-GM feed to their cows (Punt et al. 2016).

Several authors model the effects of segregation costs on product prices, consumer and producer welfare but do not consider the coexistence costs of GM farmers separately (e.g., Fulton and Giannakas 2004, Lapan and Moschini 2004, Moschini et al. 2005, Sobolevsky et al. 2005, Lapan and Moschini 2007). The effect of positive segregation costs on downstream markets in combination with farm-level ex ante and ex post regulation is discussed by Desquilbet and Poret (2014). They argue that segregation costs increase the non-GM price and hence, decrease non-GM consumers' utility making a welfare increase through coexistence costs less likely, but they do not explicitly incorporate segregation costs in their model.

The work by Sobolevsky et al. (2005) is closest to ours as they use a partial equilibrium model of differentiated consumers to analyze the market and welfare effects of costly segregation costs on GM soybean trade. Unlike Sobolevsky et al. (2005) however, our focus is on the distribution of market and welfare effects within an economy rather than on trade. We consider the different effects of coexistence and segregation costs and allow for different labeling schemes.

Whereas most theoretical approaches in the previous literature assume that both GM and non-GM products are supplied and demanded once the technology is approved, we show that the market outcome depends on the labeling as well as coexistence and segregation schemes. Our model serves as a means to analyze the market and welfare effects of regulating rapeseed derived

[6] Desquilbet and Bullock (2009) argue that non-GM production results in a loss of flexibility and therefore also creates indirect costs for the GM producers.

from NPBTs under mandatory and/or voluntary labeling schemes compared to regulating NPBTs as a conventional technique. Furthermore, we analyze the effects of coexistence costs at farm level as well as segregation costs at the level of downstream processors.

The Model

We model different regulatory systems for oilseed crops derived from NPBTs in the European Union. The model is used for an ex-ante analysis since NPBT oilseed crops have not been commercially cultivated in the European Union yet. We assume that GM and non-GM food products are vertically differentiated. Consumers perceive a GM product as a (weakly) inferior substitute for a non-GM product, that is, consumers are indifferent to or prefer non-GM products to GM products if offered at equal prices.

Although we do not model net trade of the included commodities explicitly, we consider its possible effects on market prices in a sensitivity analysis by varying the domestic supply/demand elasticities. For commodities in which the European Union is a net exporter, a modeled demand curve can be thought of as the horizontal sum of the domestic demand and the EU export demand curve. So by construction, the aggregated curve is more elastic (a similar argument holds for the supply curve and a commodity for which the country is a net importer). By varying the elasticities in the sensitivity analysis (in a later section), we can then test how sensitive our results are with respect to the inclusion of trade in commodities. The sensitivity analysis shows robust results.

We assume that the total rapeseed quantity farmers supply is processed into oil and meal, such that rapeseed is only indirectly demanded through its processed products. Rapeseed derived from NPBTs as well as its products, oil and meal, can either be of non-GM quality (N) or of GM quality (G). The quality type depends on how an NPBT is regulated (i.e., GM vs non-GM) as well as on the relevant labeling scheme (i.e., mandatory vs voluntary labeling). Processors crush rapeseed, indexed by R, to obtain oil and meal, indexed by O and M, respectively. Oil is used for human consumption, industrial use (e.g., lubricants), or biodiesel production.

We assume that consumers do not care about the use of NPBTs in rapeseed production per se but consider only how NPBTs are categorized and regulated. Hence, consumers are indifferent between crops derived by NPBTs and crops derived by conventional breeding techniques, as long as NPBT-derived crops are officially categorized and regulated as non-GM. This assumption together with vertical product differentiation imply that if NPBTs are regulated as a GM technique, NPBT-derived products must be labeled as GM and therefore some consumers are willing to pay a premium for food products produced without the GM-categorized NPBTs.[7] If, however, NPBTs are regulated as a non-GM technique, we assume that consumers perceive all the NPBT-derived products as non-GM.

The Meal Demand

Rapeseed meal is a crucial component of livestock feed. It is, therefore, closely related to most livestock food products. In what follows, we assume that the demand for meal by livestock food processors reflects consumers' preferences over the GM/non-GM characteristic. This assumption makes it possible to focus on a representative consumer's demand for meal.

The representative consumer has a quasi-linear utility $U(q_M^G, q_M^N, y)$, where q_M^G and q_M^N denote quantities of GM and non-GM products, respectively, and y denotes the consumption of the numeraire good. The quasi-linear form allows to add up the utilities for a continuum of

[7] A reason why consumers treat NPBTs as a genetic modification if they fall within the scope of the EU regulation of GMOs is that consumers cannot distinguish GM-classified crops derived by NPBTs from other GM crops (e.g., transgenic crops).

consumers of the same type without altering the properties of preferences for the GM or non-GM good. The consumption of GM and non-GM products depends on the relative price and the degree of substitutability, $\gamma \in [0,1]$. The closer γ is to zero, the more the products are differentiated. If $\gamma = 1$, products are perfect substitutes (Häckner 2000).

The consumer seeks to maximize the total surplus from consuming q_M^G and q_M^N

(0) $$\max_{q_M^G, q_M^N} U\left(q_M^G, q_M^N, y\right) - P_M^G q_M^G - P_M^N q_M^N ,$$

and the utility function takes the form as in Singh and Vives (1984)

$$U\left(q_M^G, q_M^N, y\right) = \alpha_G q_M^G + \alpha_N q_M^N - \frac{1}{2}\left(\lambda_G \left(q_M^G\right)^2 + \lambda_N \left(q_M^N\right)^2 + 2\gamma q_M^G q_M^N\right) + y ,$$

where P_M^G and P_M^N denote the price of GM and non-GM meal, respectively, and the quality parameters satisfy $\alpha_N > \alpha_G > 0$ and $\lambda_G \lambda_N - \gamma^2 > 0$. The parameters α_N and α_G represent the intrinsic quality of each product that increases the marginal utility of consuming that product. The parameters λ_N and λ_G measure the rate at which the marginal utility of consumption for a product declines with higher consumption of that product (Choi and Coughlan 2006).

Solving the consumer maximization problem (1), we obtain linear GM and non-GM demand functions

(1) $$D_M^G\left(P_M^G, P_M^N\right) = a_M^G - b_M^G P_M^G + c_M P_M^N$$

and

(2) $$D_M^N\left(P_M^G, P_M^N\right) = a_M^N - b_M^N P_M^N + c_M P_M^G$$

with parameters $a_M^G = \dfrac{\alpha_G \lambda_N - \alpha_N \gamma}{\lambda_G \lambda_N - \gamma^2}$, $b_M^G = \dfrac{\lambda_N}{\lambda_G \lambda_N - \gamma^2}$, $a_M^N = \dfrac{\alpha_N \lambda_G - \alpha_G \gamma}{\lambda_G \lambda_N - \gamma^2}$, $b_M^N = \dfrac{\lambda_G}{\lambda_G \lambda_N - \gamma^2}$, and

$c_M = \dfrac{\gamma}{\lambda_G \lambda_N - \gamma^2}$. Since both products are substitutes, the GM meal demand depends on its own price and on the non-GM meal price. Likewise, for non-GM demand.

If NPBTs are considered GM but no voluntary non-GM labeling option exists, consumers cannot distinguish (NPBT-derived) GM from non-GM products. So if GM and non-GM products are undistinguishable, we assume that consumers perceive all meal products to be of GM quality independently of the share of GM and non-GM content. As in Sobolevsky et al. (2005), we model the situation in which only GM(-perceived) meal is available by setting the non-GM price above its "choke" price, $\bar{P}_M^N = \left(a_M^N + c_M P_M^G\right) / b_M^N$, making the non-GM meal price prohibitively high (i.e., non-GM meal demand is zero). After substituting the choke price into equation (1) and denoting the single meal price as P_M, the demand for GM meal (in the absence of non-GM meal) becomes

$$(3) \qquad D_M^G \left(P_M \mid q_M^N = 0\right) = a_M^G + \frac{a_M^N c_M}{b_M^N} - \left(b_M^G - \frac{c_M^2}{b_M^N}\right) P_M .$$

For future reference, we also quantify the total demand for meal when all consumers perceive the meal to be of non-GM quality. This situation can have two causes: (i) NPBTs are regulated as non-GM, and (ii) NPBTs are unavailable to consumers either because the technique is prohibitively expensive to use (e.g., if the approval process is too expensive) or because NPBT-derived crops are banned. We provide details when this can happen in a later section describing different scenarios. The total meal demand curve in this case is obtained by summing the right-hand sides of equations (1) and (2), and recognizing that in this situation $P_M^G = P_M^N = P_M$, because there is only a single meal market price. As a result, the demand of non-GM meal (in the absence of GM meal) is

$$(4) \qquad D_M^N\left(P_M \mid q_M^G = 0\right) = \left(a_M^G + a_M^N\right) - \left(b_M^G + b_M^N - 2c_M\right)P_M \, .$$

The Oil Demand

Due to retailers' and food manufacturers' removal of GM food products, oil demand for human consumption can only be derived from non-GM rapeseed. We assume that retailers' and food manufacturers' GM food exclusion stays in place (e.g., by assuming that the costs of changing their policy is infinitely high). The mandatorily labeled and less expensive GM oil can thus only be used for industrial and biodiesel purposes; this does, however, not preclude industrial and biodiesel users from demanding non-GM oil if it is less or equally expensive than the GM counterpart. The prices of GM and non-GM oil, denoted by P_O^G and P_O^N, respectively, are determined in two separate markets as long as in the equilibrium $P_O^G < P_O^N$. On the one hand, food oil consumers can only consume non-GM oil and hence their demand $D_O^H\left(P_O^N\right)$, where H denotes human consumption, depends only on the price of non-GM oil. On the other hand, industrial and biodiesel users always demand the less expensive alternative, which in most cases is the GM oil.[8] This implies that the industrial (I) demand function D_O^I depends on $\min\left\{P_O^G, P_O^N\right\}$.

[8] Under certain conditions and under two separate oil demands it is possible that the hypothetical price of GM oil exceeds the price of non-GM oil. However, because industrial and biodiesel users are flexible in their choice of oil and decide solely on its price, the GM oil price has to equal the non-GM price.

To be consistent with the functional form of the demand functions for meal given by equations (1)-(4), we also use linear demands for food and industrial use of oil[9,10]

(5) $$D_O^H\left(P_O^N\right)=a_O^H-b_O^H P_O^N$$

and

(6) $$D_O^I\left(\min\left\{P_O^G,P_O^N\right\}\right)=a_O^I-b_O^I\min\left\{P_O^G,P_O^N\right\}.$$

The quantity of biodiesel (B) to be produced is assumed to be fixed. Because one metric ton of oil yields β_B liters of biodiesel, the oil demand for biodiesel is given by B/β_B and is therefore perfectly price-inelastic.

Rapeseed Supply

There are Z homogeneous competitive farmers in our model, similar to Sobolevsky et al. (2005), who can choose from two production technologies: GM and non-GM. Because consumers demand both GM and non-GM products in our baseline, a farmer can decide whether to produce GM or non-GM rapeseed. However, we assume a farmer does not produce both at the same time because of on-farm costs related to dual production. These costs relate, for example, to the time and money spent cleaning machinery after seeding, harvesting, transporting; or potential hurdles a farmer might face when selling non-GM rapeseed to a non-GM processor because of a higher probability of commingling of seeds. Punt and Wesseler (2015) also argue that farmers have

[9] One can think of equations (5) and (6) as linear approximations of the optimal demand functions derived from profit maximization for a production technology and given prices of the output and other inputs.

[10] It should be noted that the effective GM food removal of retailers leaves food oil consumers with only one choice, that is, non-GM oil, which means that oil demand only depends on its own price.

incentives to form GM and non-GM clubs,[11] which supports our full specialization assumption. Moreover, many voluntary labels prohibit the use of any GM feed on mixed farms that are registered as non-GM producers for parts of their animal products.

If both types of rapeseed are produced, then k farmers produce GM and the rest, $(Z-k)$, produce non-GM rapeseed. The distribution of farmers (i.e., k) is endogenous and depends on the relative price of GM and non-GM rapeseed in equilibrium. Each farmer using the GM technology produces according to the supply function $S_R^G\left(P_R^G\right)$, where P_R^G denotes the market price of GM rapeseed. Likewise, supply of each farmer producing non-GM rapeseed is $S_R^N\left(P_R^N\right)$, where P_R^N is the market price of non-GM rapeseed.

We assume lower marginal costs for GM rapeseed production, which is the main feature of first-generation GM crops (e.g., Smyth et al. 2011b, Klümper and Qaim 2014). Associated with GM production, however, are coexistence costs (e.g., isolation distance, crop rotation, potential liability costs) that the GM farmer has to bear (Venus et al. 2016). Additional costs to GM farmers are technology fees that a seed company charges to (partially) recoup the costs of the costly approval process. For reference convenience, we subsume the technological fees under the coexistence costs, noting that this aggregation does not have any qualitative implications for our results.

[11] Although the formation of a GM club would reduce the coexistence costs (e.g., keeping a minimum distance from a non-GM farmer), the costs would not be eliminated completely because the formation of a club leads to other coexistence costs, for instance, the costs the incumbent GM farmers would need to spend to convince non-GM farmers to switch to GM production.

The coexistence costs affect the farm input prices and hence pivot the GM seed supply curve.[12] We, therefore, model the coexistence costs as a percentage (θ) of the potential producer surplus (at a given GM rapeseed market price) that GM farmers forgo because of the presence of these costs. Given the functional form of the rapeseed supply we use, the coexistence costs can be implemented in our model via impacting the production of rapeseed of each GM farmer: $(1-\theta)S_R^G\left(P_R^G\right)$. Therefore, θ can alternatively be thought of as a reduction in the potential GM rapeseed production (at a given price).

The technology a farmer adopts depends on the producer surplus earned per crop. In an equilibrium in which both GM and non-GM crops are adopted, each farmer must be indifferent between the two technologies; this requires that the producer surplus be equal for each crop and farmer

$$(7) \qquad \int_0^{P_R^G}(1-\theta)S_R^G(P)dP = \int_0^{P_R^N} S_R^N(P)dP.$$

Finally, the total supply of GM rapeseed is $k(1-\theta)S_R^G\left(P_R^G\right)$ and the total supply of non-GM rapeseed is $(Z-k)S_R^N\left(P_R^N\right)$.

Scenarios Description and Market Equilibriums

We consider four scenarios summarized in table 1. Scenario 1 is the baseline scenario reflecting the current labeling policies and practices in the EU. In both scenario 1 and scenario 2, NPBTs are regulated as a GM technique and mandatory labeling of food oil applies. The two scenarios differ in the treatment of meal. In scenario 1, a voluntary non-GM labeling scheme is available, which gives rise to separate GM and non-GM meal markets. In scenario 2, a voluntary labeling

[12] One can also think of coexistence costs as an additional input cost to GM rapeseed production.

option is absent and hence only a single market for GM meal exists. In scenario 3, NPBTs are regulated as a non-GM technique and hence all farmers default to this less costly technology whereas consumers perceive all products as non-GM. Scenario 4 assumes that NPBTs are banned (or coexistence costs are prohibitively high), so that all farmers use the conventional technology, which consumers, of course, perceive as non-GM.

<Table 1 around here.>

Scenario 1: NPBTs Regulated as GM & Mandatory Oil Labeling & Voluntary Meal Labeling

The processor buys GM or non-GM rapeseed at price P_R^G or P_R^N, respectively. After the crushing, one metric ton of rapeseed yields β_O metric tons of oil and β_M metric tons of meal ($\beta_M = 1 - \beta_O$). We assume no differences in the oil and meal content per ton between GM and non-GM rapeseed. We also assume constant processing cost per ton of rapeseed (other than the feedstock price) and denote it by c_R; the processing cost is the same for both types of rapeseed. The GM (or non-GM) rapeseed processing yields revenues from selling oil and meal at market prices P_O^G (or P_O^N) and P_M^G (or P_M^N), respectively. The constant returns to scale technology implies zero marginal profits for the crusher, and enables to express the GM rapeseed price as

(8) $$P_R^G = \beta_O P_O^G + \beta_M P_M^G - c_R.$$

The price relationship for the non-GM branch of the supply chain is very similar, but includes additional segregation costs for oil (s_O) and meal (s_M)

(9) $$P_R^N = \beta_O \left(P_O^N - s_O \right) + \beta_M \left(P_M^N - s_M \right) - c_R.$$

The segregation costs represent, for example, non-GM processors' increased collection and transport costs as well as auditing, inspection, and certification costs to guarantee the non-GM quality (e.g., Gabriel and Menrad 2015). We model the segregation costs as a production tax in a given final product market, and therefore subtract them from the market price of oil and meal the crusher receives.

The GM market clearing condition equilibrates the total supply of GM oil with its total demand. The GM oil supply is given by the total GM rapeseed supply multiplied by the share of oil, β_O, in rapeseed. The demand consists of the oil needed to produce *B* liters of biodiesel (where one ton of oil yields β_B liters of biodiesel) and the industrial use of oil (e.g., oil used for lubricants), yielding

$$(10) \qquad \beta_O k(1-\theta) S_R^G\left(P_R^G\right) = \frac{B}{\beta_B} + D_O^I\left(\min\left\{P_O^G, P_O^N\right\}\right).$$

Because for industrial users, GM and non-GM oils are perfect substitutes, it is possible that some non-GM oil is used in the industry if non-GM oil prices happen to equal the GM oil prices.

Due to retailers' exclusion of GM food products, only non-GM oil is used for human consumption. The non-GM oil market clearing condition is

$$(11) \qquad \beta_O (Z-k) S_R^N\left(P_R^N\right) = D_O^H\left(P_O^N\right).$$

The market clearing conditions for GM and non-GM meal are represented by

$$(12) \qquad \beta_M k(1-\theta) S_R^G\left(P_R^G\right) = D_M^G\left(P_M^G, P_M^N\right)$$

and

$$(13) \qquad \beta_M (Z-k) S_R^N\left(P_R^N\right) = D_M^N\left(P_M^G, P_M^N\right),$$

respectively. It should be noted that the farm-level coexistence costs are included in the GM rapeseed supply function, whereas the segregation costs are part of the zero-profit condition of the non-GM rapeseed processor. Hence, the segregation costs are not explicit in the market equilibrium conditions. The market equilibrium for scenario 1 is determined by solving the system of equations (7)-(13) for prices $P_R^G, P_R^N, P_O^G, P_O^N, P_M^G, P_M^N$, and the number of GM farmers k.

Scenario 2: NPBT Regulated as GM & Mandatory Oil Labeling & No Voluntary Meal Labeling

In the second scenario, we model the effects of regulating NPBTs as GM in the absence of a voluntary non-GM labeling option for meal-derived livestock products. Without non-GM labeling, consumers cannot distinguish GM or non-GM meal-derived products and so we assume that consumers perceive meal-derived products as GM regardless of the share of GM and non-GM meal the products contain. Therefore, there is only one market price of meal denoted by P_M. The meal market clearing condition in this case is

(14) $$\beta_M k(1-\theta)S^G\left(P_R^G\right)+\beta_M\left(Z-k\right)S^N\left(P_R^N\right)=D_M^G\left(P_M \mid q_M^N=0\right),$$

where the left-hand side represents the sum of GM and non-GM meal supply, and the right-hand side represents the total meal demand (for which in the empirical part of the article we use equation (3)). The absence of the voluntary labeling option further affects the zero-profit condition of the processors since meal needs not be segregated, such that $s_M = 0$, and there is only a single meal price; hence we have

(15) $$P_R^G=\beta_O P_O^G+\beta_M P_M-c_R$$

and

(16) $$P_R^N=\beta_O\left(P_O^N-s_O\right)+\beta_M P_M-c_R.$$

The market-clearing condition for oil is unaffected by the absence of the non-GM labeling scheme, and hence the system of equations (7), (11), and (14)-(16) in unknowns $P_R^G, P_R^N, P_O^G, P_O^N, P_M$, and k constitutes the equilibrium for scenario 2.

Scenario 3: NPBTs Regulated as Non-GM

In this scenario, there is no differentiation between GM and non-GM, and hence, no labeling or coexistence costs. Therefore, the single zero-profit condition of processors is

(17) $$P_R = \beta_O P_O + \beta_M P_M - c_R.$$

Since there is no GM/non-GM quality distinction of oil and meal, all *Z* farmers produce only the rapeseed derived by NPBTs, as this can be produced at lower marginal costs. Since all suppliers are using NPBTs, there are neither segregation nor coexistence costs. Similar to the meal market in scenario 2, processors offer only a single oil type at price, P_O. This oil price is charged to food as well as industrial consumers. The oil market clearing condition is

(18) $$\beta_O Z S_R^G\left(P_R\right) = D_O^H\left(P_O\right) + \frac{B}{\beta_B} + D_O^I\left(P_O\right),$$

where the left-hand side represents the total oil supply and the right-hand side the pooled demand for human oil consumption, biodiesel production, and industrial oil consumption. Also, the meal equilibrium of scenario 3 differs from scenario 2 in that consumers perceive NPBTs according to the regulation as non-GM and so they also perceive the meal-derived product as non-GM. Hence, the demand function in scenario 3 is D_M^N instead of D_M^G. The market clearing condition is

(19) $$\beta_M Z S_R^G\left(P_R\right) = D_M^N\left(P_M \mid q_M^G = 0\right).$$

Notice that the rapeseed supply function in equations (18) and (19) is denoted S_R^G. Even though NPBTs are considered as non-GM in this scenario, we use the index *G* in the supply function to be consistent with the notation in the previous scenarios to mean that farmers are using the less-costly biotechnology-based NPBT. In scenario 3, we solve equation system (17)-(19) for prices P_R, P_O, and P_M.

Scenario 4: NPBTs Are Banned

In this scenario, we consider the case in which NPBTs are banned and so all farmers default to the non-GM technology. This scenario is very similar to scenario 3. The similarities are: all farmers use the same technology; there are no segregation and coexistence costs; there is only a single rapeseed, meal, and oil price; and all consumers perceive the products as non-GM. Scenario 4 differs from scenario 3 in that farmers use the costlier non-GM technology, and hence, their supply function is S_R^N instead of S_R^G. The market-clearing condition for oil is

$$(20) \qquad \beta_O Z S_R^N\left(P_R\right)=D_O^H\left(P_O\right)+\frac{B}{\beta_B}+D_O^I\left(P_O\right),$$

and the market-clearing condition for meal is

$$(21) \qquad \beta_M Z S_R^N\left(P_R\right)=D_M^N\left(P_M \mid q_M^G=0\right).$$

The system of equations (20) and (21), together with the zero-profit condition, equation (17), in unknowns P_R, P_O, and P_M constitutes the equilibrium for scenario 4.

Calibration of the Baseline

We calibrate our model to scenario 1 in the absence of segregation and coexistence costs, which then constitutes the model baseline. We use the observed and derived prices and quantities for the European Union in the year 2013. We calibrate to scenario 1 as this is the most general scenario, in which NPBTs are regulated as GM and both mandatory GM and voluntary non-GM labeling schemes are in place. The calibration to the most general scenario makes it possible to use the calibrated parameters later in simulating the other scenarios.

In scenario 1, NPBT-derived crops are categorized GM and conventionally produced crops are considered non-GM. But since up to now, all rapeseed in Europe is conventional (and therefore non-GM), we assume for the calibration that the observed prices are non-GM commodity prices (P_R^N , P_O^N , and P_M^N) but that the observed quantities are GM and non-GM quantities. From this assumption, we calculate the equilibrium GM-categorized NPBT prices P_R^G , P_O^G , and P_O^N .

We assume that the price for rapeseed derived by NPBTs is lower than the conventional rapeseed price, because NPBT crops are produced at lower marginal costs. Estimates of the variable cost differences, for example, for GM and non-GM canola in Canada show mixed results; benefits, such as easier weed control and better time management, are often difficult to quantify (Qaim 2009, Smyth et al. 2011a). Yield increases and cost reductions through reduced expenditures on herbicides, fuel, and labor have been reported for herbicide-resistant canola in Canada, USA, and Australia to be higher for the more recent years as compared to the early years after the introduction (Brookes and Barfoot 2016). We assume a 10-percent cost advantage for GM rapeseed, which represents an average estimate for GM canola for the years 2004 to 2014 as reported by Brookes and Barfoot (2016). The cost advantage implies $P_R^G = P_R^N / 1.10$ and is assumed to be a result of differences in production costs for competitive farmers, whereas coexistence and segregation costs are assumed to be zero in the calibration.

We assume an equal percentage price advantage for GM oil and meal as compared to their non-GM counterparts. The estimated price advantage must be such, that the crushing costs of GM and non-GM crops are equal. Denoting the relative price premium by *x*, GM oil and meal prices in the absence of segregation costs (i.e., $s_O = s_M = 0$) satisfy $P_O^G = P_O^N / (1+x)$ and $P_M^G = P_M^N / (1+x)$, respectively. To meet the non-GM zero-profit condition of rapeseed processors in equation (9), the premium is found by rewriting the GM zero-profit condition in equation (8) into $P_R^G = \left(\beta_O P_O^N + \beta_M P_M^N\right) / \left(1+x\right) - c_R$. Using the observed prices P_O^N and P_M^N and recalling that

$P_R^G = P_R^N / 1.10$, we obtain, $x \approx 8.8$ percent. We assume that the price a processor pays for rapeseed equals the price a farmer receives.

Table 2 summarizes the values of technical coefficients, prices, crushing costs, and the number of GM farmers used to calibrate the model to scenario 1. The number of GM farmers, *k*, can be thought of as a percentage of the total number of rapeseed farmers, *Z*, when $Z = 100$. The number of GM farmers is endogenously determined in the calibration (Appendix A1). Changing the total number of farmers would affect *k* but not the share of GM farmers, k / Z.

Rapeseed contains about 43 to 46 percent oil. However, not all oil is extracted during crushing. The extracted oil amount varies between 30 and 43 percent, depending on the type of crushing and pressing of the rapeseed (Ferchau 2000, Grau et al. 2010). We set the technical oil and meal coefficients to $\beta_O = 0.38$ and $\beta_M = 1 - 0.38 = 0.62$, respectively. Using the observed non-GM prices as well as the technical oil and meal coefficients, we derive the crushing costs from the zero-profit condition in equation (9). These derived crushing costs are 51.20 euros per metric ton, which is in line with estimates by Ferchau (2000).

<Table 2 around here.>

The total rapeseed net-supply in 2013 was 25.09 million metric tons (European Commission 2014). After rapeseed crushing, 2.80 million tons of oil were demanded as food for human consumption. The oil used for biodiesel consumption is calculated by multiplying the share of rapeseed oil in total biodiesel feedstock of 55.67 percent (USDA FAS 2015) by the total amount of vegetable oil, 8.51 million tons (FEDIOL 2013) that was used as feedstock for biodiesel. This calculation yields a biodiesel quantity of 5,202 million liters derived from 4.74 million tons of rapeseed oil. To meet the total rapeseed net-supply we categorize the remaining rapeseed oil of 1.99 million tons as demand for industrial use. By applying the technical coefficients, crushing and pressing of the total rapeseed net-supply yields 15.55 million tons of meal of which 10.98 million tons are calculated (using the model equations) to be GM and the remainder, 4.57 million tons, is non-GM meal. Given the different demands, the division of rapeseed into GM and non-GM can be derived from the baseline (scenario 1) equation system to be 17.52 and 7.57 million tons, respectively. Table 3 summarizes the supply and demand quantities used in the calibration.

<Table 3 around here.>

Supply and demand elasticities are taken from the FAPRI elasticity database.[13] We use constant price elasticity supply curves for GM and non-GM rapeseed. For a sensitivity analysis, we take these elasticities as the mean values of a *beta* distribution (Davis 2008) from which random values are drawn in 10,000 simulations. Table 4 shows the supply and demand elasticity parameters as well as the mean, minimum, and maximum value of the *beta* distribution. One of the restrictions in our sensitivity analysis is that the own-price elasticity of GM rapeseed supply must be greater than the own-price elasticity of non-GM rapeseed supply. This requirement reflects the effect of the NPBT in lowering the marginal production costs. Furthermore, own- and cross-price elasticities for meal demand are chosen to satisfy the restrictions imposed on the parameters of the underlying utility function.

<Table 4 around here.>

Simulation and Results

We start by investigating the welfare implications of individual scenarios (1 to 4) in the absence of segregation and coexistence cost effects as presented in block A of tables 5 and 6. To that end, we first simulate the market and welfare effects of removing the voluntary non-GM labeling

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[13] http://www.fapri.iastate.edu/tools/elasticity.aspx

option for meal in case NPBT-derived rapeseed is regulated as GM; that is, we compare scenario 2a with the calibrated scenario 1a (=baseline). Second, we analyze the effect of regulating NPBTs as a non-GM technique by comparing scenario 3a with the baseline. Finally, we analyze the effects of banning NPBTs by comparing scenario 4a with the baseline. Table 1 above summarizes the details of individual scenarios. Blocks B, C, and D of tables 5 and 6 show the effects of oil segregation costs, meal segregation costs, and coexistence costs, respectively.

Following the estimates by Tillie and Rodriguez-Cerezo (2015) for soybean meal, we set the segregation costs of meal to 20 percent of the non-GM meal price. For oil, we assume segregation costs of 10 percent. In a study of the German rapeseed oil industry, these costs were found to vary widely, depending on factors like storage, elevation systems, processing strategies, and monitoring arrangements (Gabriel and Menrad 2015). We set the coexistence costs (including the technology fee) to 5 percent ($\theta = 0.05$) to show their qualitative effects. The 5 percent coexistence costs corresponds to 50.5 euros per ha assuming an average rapeseed yield of 3.1 metric tons per ha.[14] However, the coexistence costs (incl. the technology fee) for rapeseed under current coexistence policies are likely to be higher (e.g., Gabriel and Menrad 2015), and may even outweigh farmers' marginal cost benefits of growing NPBT rapeseed; this case would enforce scenario 4a, in which farmers do not grow NPBTs. Since there are no qualitative insights into the effects of coexistence costs if we set them too high, we show the effects of 5 percent in block D of tables 5 and 6 and analyze the effects of increasing these costs to find the maximum coexistence costs in a sensitivity analysis.

[14] The average rapeseed yield in the European Union in 2012 (http://ec.europa.eu/agriculture/statistics/agricultural/2013/pdf/d04-1-44_en.pdf). We show the details of calculating the coexistence costs per ton of rapeseed in the section on the welfare effects of coexistence costs.

Table 5 shows the market effects of different scenarios and table 6 shows the changes in the welfare components. The changes are in comparison to baseline scenario 1a.

<Table 5 around here>

<Table 6 *around here.>*

The Effects of No Voluntary Non-GM Labeling Scheme

A comparison of scenario 2a to 1a in table 6 shows that abolishing the voluntary non-GM labeling option for meal-derived livestock products makes all producers and consumers worse off, except the overall meal consumers, who are better off by 164 million euros. This is a surprising result as one would expect that non-GM meal consumers lose from not having access to the products of their preference. Figure 1 below explains that the consumer surplus gain is mainly driven by the decreased meal price.

<Figure 1 around here.>

The GM (non-GM) demand curve in figure 1 is conditional on the equilibrium prices of the non-GM (GM) product. Using the calibrated intercepts and slopes for equations (1) and (2) as well as the equilibrium GM and non-GM prices, we obtain

$D_M^G\left(P_M^N\right)=\left(56.57+0.015P_M^N\right)-0.203P_M^G=60.414-0.203P_M^G$, and

$D_M^N\left(P_M^G\right)=\left(21.594+0.015P_M^G\right)-0.078P_M^N=25.126-0.078P_M^N$.

The equation for the pooled meal demand curve (corresponding to equation (3)) turns out to be $D_M^G=60.607-0.201P_M$. Notice that, because the substitution parameter $\gamma\in[0,1]$, the intercept of the inverse pooled demand curve is between the GM and non-GM inverse demand intercepts. The prices P_M^G, P_M^N, and P_M correspond to equilibriums related to the three demand curves above.

The total meal consumer surplus in scenario 2a is represented by area *ghi*, which is greater than the sum of areas *abc* and *def*, corresponding to the consumer surpluses of non-GM and GM meal in scenario 1a.

Everything else held constant, the immediate effect of a lower meal price is to reduce the rapeseed price and hence the rapeseed supply. A reduced rapeseed supply yields a lower oil supply, which drives oil prices up. The decreased rapeseed price and increased oil price cause a loss in producer and oil consumer welfare in comparison to scenario 1a. The sum of these losses outweighs the meal consumer surplus gain, so that the abolition of a voluntary non-GM label reduces overall welfare by 212 million euros (table 6).

The Effects of Regulating NPBTs as Non-GM

Regulating NPBT-derived crops as non-GM is the only scenario that increases total welfare as compared to baseline. In scenario 3a (third column in block A of tables 5 and 6) all farmers use NPBTs for two reasons: first, rapeseed derived by NPBTs is treated as non-GM, and, second, the marginal cost of production is lower for NPBTs. This implies that farmers have no incentive to use the costlier conventional technology for which they would get no price premium. Since all farmers are using the marginal cost-reducing technology, the rapeseed supply increases, driving down rapeseed, oil, and meal prices. Producers lose and consumers gain from the lower prices as compared to scenario 1a. The gain in oil and meal consumer surplus outweighs the loss in producer surplus, such that regulating NPBTs as non-GM leads to an overall welfare gain of 315 million euros.

The Effects of Oil Segregation Costs

Scenarios 1b and 2b in table 5, show that oil segregation costs increase the non-GM oil consumer price, which reduces the quantity of oil demanded for human consumption. A lower non-GM oil consumption drives down the non-GM rapeseed price and hence also the supplied non-GM rapeseed quantity. Furthermore, a lower supply of non-GM rapeseed reduces the non-GM meal supply, leading to an increase in the non-GM meal price. This result is in line with Sobolevsky et al. (2005) who show that food consumers and producers benefit from low segregation costs. However, our results (1b and 2b) show that not all consumers benefit from low segregation costs.

When segregation costs increase, more farmers produce GM rapeseed. A larger GM rapeseed supply drives down GM rapeseed prices, which leads to a lower GM oil price and hence more industrial oil and biodiesel consumption. Because the GM oil price with segregation costs (734.7 euros per metric ton) in scenario 1b in table 5 is lower than the GM oil prices without segregation costs in the baseline (755.5 euros per metric ton), GM oil consumers benefit from segregation costs. But the total welfare change with segregation costs in scenarios 1b and 2b is negative.

By further comparing scenario 1b with 1a and scenario 2b with 2a, we see that the market and welfare effects of oil segregation costs are similar for partial labeling (no non-GM labeling) and full labeling (with non-GM labeling), respectively. Producers and non-GM consumers lose and GM consumers gain. In scenario 2b, the producer and non-GM oil consumer losses due to segregation costs are added to the losses due to the non-GM label abolishment. The GM consumers' gains due to oil segregation costs, on the other hand, outweigh their losses due to the non-GM label abolishment. Finally, the gain meal consumers get due to the abolishment of the non-GM label (scenario 2a) is slightly lower with oil segregation costs (scenario 2b).

The Effects of Meal Segregation Costs

Table 5 and 6 show that in scenario 1, meal segregation costs of 20 percent of the non-GM meal price have very similar effects than oil segregation costs of 10 percent of the non-GM oil price.

This similarity is due to the similarity between the levels of the segregation costs for oil and meal: $\beta_O \times 0.1 \times P_O^N = 31.2$ and $\beta_M \times 0.2 \times P_M^N = 32.8$. The welfare effects of segregation costs are that non-GM consumers and producers lose and GM oil and meal consumers gain. However, meal segregation costs apply only in scenario 1 because in scenario 2 the total meal supply is pooled. This pooling effect when abolishing the non-GM meal labeling option has important implications.

Comparing scenario 1c with 1a and 2a in table 6, we find that if meal segregation costs are sufficiently high, producers and some consumers would benefit from the abolishment of the non-GM label (i.e., their surplus in 1c exceeds their surplus in 1a). For example, oil consumers' surplus loss from not having the voluntary labeling scheme (i.e., scenario 2a) is 115 million euros. But their surplus loss from having the scheme in the presence of meal segregation costs (i.e., scenario 1c) is even high, that is, 162 million euros. Similarly, producers' loss from not having the label is 200 million euros whereas their loss from having the label in the presence of meal segregation costs is 216 million euros. As shown above, meal consumers clearly gain (164 million euros in scenario 2a) from not having the voluntary label. This effect is even stronger with meal segregation costs.

In summary, our comparison implies that producers and non-GM oil consumers benefit from a voluntary non-GM label, as long as meal segregation costs are sufficiently small. This result is consistent with the one by Fulton and Giannakas (2004). However, when high segregation costs are added to the baseline, these consumers and producer are better off without voluntary labeling. GM oil consumers (i.e., industrial use and biodiesel) are worse off (by 18 and 44 million euros, respectively) from not having the voluntary label so they benefit from the label. Their benefit is even higher, when meal segregation costs are high.

The Effects of Coexistence Costs

Coexistence costs decrease GM rapeseed, oil, and meal supply, which leads to price increases in the GM commodities (cf. scenarios 1d and 2d in table 5). The increase in the GM rapeseed price drives up the non-GM rapeseed price because each farmer is assumed to be indifferent between producing the GM or non-GM rapeseed variety. The increased non-GM rapeseed prices increase non-GM oil and meal prices, which decreases non-GM quantities demanded.

All consumers in scenario 1d and 2d are worse off due to the increased prices caused by coexistence costs as compared to the situation without coexistence costs. Comparing scenario 1d with the baseline, GM rapeseed farmers benefit from coexistence costs because the GM price increase of 31.5 euros (from 386.6 to 418.1) causes a surplus gain that exceeds the surplus loss due to coexistence costs. Since a farmer is indifferent between GM and non-GM rapeseed production, the non-GM rapeseed price also increases by 18.2 euros (from 425.3 to 443.3) such that the non-GM surplus gain equals the GM net-surplus gain (i.e., the difference between the GM surplus and the coexistence cost).

Notice that the GM price increase is greater than the non-GM price increase. Similarly, the GM oil price also increases faster than the non-GM oil price with higher coexistence costs. This effect is shown in figure where the percentage coexistence costs are translated into costs per hectare. This can be done by first computing GM farmers total surplus and multiplying by θ. The 5 percent, as used in tables 5 and 6, correspond to total coexistence costs of 287 million euros (not presented in the tables). Dividing the coexistence costs by the total GM rapeseed quantity of 17.57 million tons (cf. column 1d in table 5), we get 16.30 euros per ton or 50.53 euros per hectare (assuming a rapeseed yield of 3.1 ton per hectare). Similarly, we can translate, for example, 1 percent coexistence costs into 9.11 euros per hectare and 10 percent into 115.79 euros per hectare.

The GM oil price approaches the non-GM oil price faster than does the GM rapeseed price the non-GM rapeseed price. Once the coexistence costs reach 8.6 percent (95.80 euros per hectare) in the absence of segregation costs, the GM and non-GM oil prices would intersect, which cannot happen because the condition, $P_O^G \leq P_O^N$, of vertical product differentiation must hold. This condition is always satisfied, since the value of our industrial oil demand function is $D_O^I\left(\min\left\{P_O^G, P_O^N\right\}\right)$. Whenever the GM oil price would exceed the non-GM oil price, biofuel and industrial oil consumers would buy non-GM oil until its price equalizes with the GM price. Hence, for the case in which coexistence costs exceed 8.6 percent, we have $P_O^G = P_O^N$.

<Figure 2 around here.>

Once coexistence costs reach a threshold of 12.6 percent (157.01 euros per ton), also the rapeseed prices equalize. This point constitutes the maximum coexistence costs (for our baseline values) under which both GM and non-GM crops are cultivated. Increasing the coexistence costs beyond this maximum would cause GM rapeseed and meal prices to exceed non-GM prices—a price relation that would contradict the conditions of vertical production differentiation. Hence all farmers switch to non-GM crops, that is, they switch to scenario 4a. This switch explains the discontinuity in figure at the 12.6 percent coexistence cost. Scenario 4a is identical to scenario 3a, except now farmers are only using the conventional technology instead of NPBT. The conventional technology yields a lower total rapeseed supply, which increases commodity prices. Farmers benefit from these higher prices while all consumers lose. This is in line with Fulton and Giannakas (2004) who show that consumers benefit from a situation without labeling (i.e., regulating NPBTs as conventional in our case) when consumer aversion is low.

Sensitivity Analysis and Discussion

The simulation shows that increased productivity through NPBTs has a price decreasing effect that makes farmers worse off and consumers better off. For testing the robustness of our results, we ran a Monte Carlo simulation with 10,000 random draws of elasticities from a beta distribution. The mean, minimum, and maximum values of the distribution are reported in table 4. In each simulation, we calculate the market and welfare changes. Table A.2 in the Appendix A2 shows the 10 and 90 percent range of the resulting welfare changes distribution. None of the signs change within the ranges. This sign consistency indicates robust results.

A decrease in the producer surplus from technological improvement may seem counter-intuitive. However, for inelastic demands, the surplus loss due to a price decrease when switching from non-GM to GM production (e.g., switching from scenario 4a to scenario 3a) outweighs the surplus gain due to lower marginal costs. On the other hand, elastic demand leads to a greater surplus gain due to reduced marginal costs (from the GM technology) than the surplus loss due to a price decrease. Hence, an elastic demand can reverse the producer surplus effect (e.g., Duncan and Tisdell 1971, Martin and Alston 1997). This reverse effect is shown in table A.3 in the Appendix, where we report welfare changes of table 6 for a price elasticity of demand for human oil consumption of -3.0.

An elastic demand also reduces the positive effect of coexistence costs. Whereas under the elastic oil demand the producer welfare effect of coexistence costs is lower but still positive in scenario 1, it is negative is scenario 2. Segregation costs, on the other hand, have a much stronger negative effect on producer welfare under an elastic oil demand. This negative effect, caused by segregation costs, is compensated for by higher consumer surpluses as compared to inelastic oil demand.

Finally, it may also seem counter-intuitive that a voluntary non-GM label for meal-derived products reduces overall surplus of meal consumers. However, the model only allows to make a point about the overall meal consumers and does not allow to distinguish by how much GM and non-GM meal consumers benefit or lose separately. What we can say with the model is that all consumers who consume GM meal in the baseline are better off in without the non-GM labeling option (scenario 2a) due to the lower meal price. Furthermore, some of the initial non-GM consumers also benefit in scenario 2a from the reduced price, so that they do not mind consuming GM instead of non-GM meal. However, some of the initial non-GM consumers may leave the rapeseed meal market and switch to a substitute market. These consumers are the ones that are worse off by abolishing the voluntary labeling scheme. We estimate only the overall meal consumer surplus change, which is positive when abolishing voluntary labeling.

Discussion and Conclusions

We develop a partial equilibrium model to analyze the market and welfare effects of regulating new plant breeding techniques (NPBTs) as GM or non-GM technologies. We apply the model to the EU market of rapeseed and commodities derived thereof: meal and oil. The market and welfare effects are analyzed under a mandatory label for GM food products and a voluntary label for meal-derived livestock products. Both labels apply in the baseline. A key feature of our model is that it allows us to separate the effects of farm-level coexistence cost and marketing-level segregation and identity preservation costs.

In general, the model shows that regulating NPBTs as GM generates an overall welfare loss as compared to regulating them as non-GM. This is because when NPBT crops are regulated as GM (as compared to non-GM), prices are higher and consumers' welfare loss outweighs producers' gains. Increasing coexistence costs intensifies this effect and may even lead to the absence of NPBTs if the costs pass a certain threshold. Unlike coexistence costs, segregation costs, do not increase all prices but actually lower the price of GM rapeseed oil (benefiting industrial and biodiesel consumers) as well as the rapeseed prices received by farmers. The prices of food oil and meal increase due to segregation costs, however.

We show that vertical product differentiation of meal-derived livestock products through a voluntary non-GM labeling scheme, which some EU Member States have developed, substantially increases the meal price and hence makes overall meal consumers worse off. But industrial oil and biodiesel consumers benefit from voluntary meal labeling. Also farmers and food oil consumers benefit from the voluntary labeling scheme. However, we show that these farmers and food oil consumers are only better off if meal segregation costs do not exceed a threshold level. When meal segregation costs exceed that threshold only industrial and biodiesel consumers benefit from voluntary meal labeling.

Coexistence costs have an overall welfare decreasing effect. We show that even if the use of NPBTs lowers farmers' marginal rapeseed production costs by 10 percent, they would not cultivate these crops if the coexistence costs (including the technology fees in the form of higher seed costs for the NPBT seeds) exceed a threshold of around 157 euros per hectare. Under current coexistence policies in most EU Member States, coexistence costs are likely to exceed this level (Venus et al. 2016). These results imply that if NPBTs are regulated as GM in the European Union, the cultivation of such crops is likely to be unprofitable under the current labeling and coexistence policies.

An important assumption of our model is that consumers only care about the regulation of NPBTs but not about NPBTs per se. However, very little is known about how consumers would behave if NPBTs were actually marketed. If consumers do care about NPBTs per se, they might be willing to pay a premium to avoid NPBT-derived products even if these products are regulated as non-GM. If this is the case, the industry may develop voluntary labeling schemes to avoid

NPBTs (similar to the non-GM labeling schemes for livestock products). This, however, requires to set up a segregation system including coexistence measures at farm-level. Our model actually covers this case in the scenario 1 except that food oil, in this case, may also be vertically differentiated into an NPBT and a non-NPBT food oil market. While segregation and coexistence costs would still be necessary to segregate NPBT from non-NPBT products, the approval costs would be much lower than if NPBT-derived rapeseed is categorized as GM product.

Overall, the results show that a ban on NPBTs is the most costly strategy in which consumers lose and farmers gain the most. This illustrates that farmers may not lobby for NPBTs. On the consumer side, the biodiesel industry complex would be the one losing most and have a strong incentive to lobby for NPBTs (even in the presence of labeling policies). Looking at the gains and losses, regulating the NPBTs as a non-GM technology generates the largest welfare benefits and would be in line with the requests by many scientists.

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Table 1. Overview of the Four Scenarios of NPBT Regulation and Labeling

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Categorization of NPBTs	G	G	N	banned
Food oil labeling	mandatory	mandatory	-	-
Meal-derived product labeling	voluntary	-	-	-
Technology used by farmers	NPBT & conv	NPBT & conv	NPBT	conv
Coexistence costs	✓	✓	-	-
Oil segregation cost	✓	✓	-	-
Meal segregation cost	✓	-	-	-
Consumers perceive … as				
…Food oil	N	N	N	N
…Industrial oil	G	G	N	N
…Meal-derived food	G & N	G	N	N

Note: "G" = GM, "N" = non-GM, "conv" = conventional, "✓" = applies, "-" = does not apply

Table 2. Values of Technical Coefficients, Prices, Crushing Costs, and Number of Farmers for the Model Calibration

Description	Symbol	Value	Source/explanation
Oil yield from crushing one metric ton of rapeseed (metric tons)	β_O	0.38[a]	Ferchau (2000) and FEDIOL (2013)
Meal yield from crushing one metric ton of rapeseed (metric tons)	β_M	0.62[a]	$1-\beta_O$
Liters of biodiesel from a metric ton of rapeseed oil	β_B	1,098.08	CARD (2016)
Price of GM rapeseed (€/metric ton)	P_R^G	386.59	$P_R^G = P_R^N / 1.10$
Price of non-GM rapeseed (€/metric ton)	P_R^N	425.25	Average price for 2013, UFOP (2013)
Price of GM oil (€/metric ton)	P_O^G	755.46	$P_O^G = P_O^N / 1.088$
Price of non-GM oil (€/metric ton)	P_O^N	822.17	Average price for 2013, UFOP (2013)
Price of GM meal (€/metric ton)	P_M^G	243.12	$P_M^G = P_M^N / 1.088$
Price of non-GM meal (€/metric ton)	P_M^N	264.58	Average price for 2013, UFOP (2013)
Crushing cost (€/metric ton)	c_R	51.20	$c_R = \beta_O P_O^N + \beta_M P_M^N - P_R^N$
Total number of farmers	Z	100.00	Assumed
Number of GM farmers	k	67.80	Calculated

[a] The amount of oil and meal from crushing rapeseed can vary, depending on the type of rapeseed crushing/pressing.

Table 3. Supply and Demand Quantities for Model Calibration

Description	Symbol	Value	Source/explanation [a]
Total supply of GM rapeseed	kS_R^G	17.72	Calculated [b]
Total supply of non-GM rapeseed	$\left(Z-k\right)S_R^N$	7.37	Calculated [b]
Demand for oil for human consumption (metric tons)	D_O^H	2.80	FEDIOL (2013)
Demand for oil for industrial consumption (metric tons)	D_O^I	1.99	Calculated
Oil for biodiesel demand (metric tons)	B/β_B	4.74	USDA FAS (2015) and FEDIOL (2013)
Demand for meal GM (metric tons)	D_M^G	10.98	Calculated
Demand for meal non-GM (metric tons)	D_M^N	4.57	Calculated

[a] See text for further explanation on the calculations, [b] The sum of calculated GM and non-GM rapeseed supply equals 2013 rapeseed supply (USDA FAS 2015).

Table 4. Parameters and Baseline Elasticity Values for Model Calibration

Description	Parameter	Mean	Min	Max
Own-price elasticity of GM rapeseed supply	ε_R^G	0.35[b]	0.10	0.80
Own-price elasticity of non-GM rapeseed supply	ε_R^N	0.30[a]	0.10	0.80
Own-price elasticity of GM oil demand for industrial use	η_O^I	-0.38[a]	-1.00	-0.10
Own-price elasticity non-GM rapeseed oil demand for human consumption	η_O^H	-0.25[a]	-1.00	-0.10
Own-price elasticity of GM meal demand	η_M^G	-4.50[b]	-5.00	-0.80
Own-price elasticity of non-GM meal demand	η_M^N	-4.50[b]	-5.00	-0.80
Cross-price elasticity of demand	$\eta_M^{crossNG}$	0.35[b]	0.01	1.00

Source: [a] FAPRI (2013), [b] assumed to satisfy the conditions of the quasi-linear utility function for vertical product differentiation.

Table 5. Market Effects of NPBT Regulation under Various Scenarios

	A. Labeling effects w/o segregation and coexistence costs				B. With 10% oil segregation cost		C. With 20% meal segregation cost	D. With 5% coexistence cost	
	S.1a	S.2a	S.3a	S.4a	S.1b	S.2b	S.1c	S.1d	S.2d
Meal segregation cost (€/ton)	0	-	-	-	0	-	52.9	0	-
Oil segregation cost (€/ton)	0	0	-	-	82.2	82.2	0	0	0
Coexistence cost for rapeseed	0	0	-	-	0	0	0	0.05	0.05
Number of farmers									
Number of NPBT farmers	67.8	68.2	100.0	0.0	68.4	68.9	68.5	68.9	69.3
Prices (€/ton)									
Price of GM rapeseed	386.6	378.9	365.7	-	378.7	370.9	378.3	418.1	410.0
Price of non-GM rapeseed	425.3	416.5	-	493.9	416.2	407.4	415.8	443.5	434.5
Price of GM oil	755.5	764.6	693.8	-	734.7	742.9	733.6	837.6	845.0
Price of non-GM oil	822.2	863.5	-	1,024.5	878.2	921.0	881.0	868.0	909.6
Price of GM meal	243.1	225.1	247.2	-	244.1	225.6	243.1	243.6	226.0
Price of non-GM meal	264.6	-	-	251.3	266.1	-	266.2	265.9	-
Quantity supplied (Mtons)									
Rapeseed GM per farm	0.26	0.26	0.26	-	0.26	0.26	0.26	0.26	0.25
Rapeseed non-GM per farm	0.23	0.23	-	0.24	0.23	0.23	0.23	0.23	0.23
Rapeseed GM total	17.72	17.70	25.63	-	17.75	17.74	17.75	17.57	17.56
Rapeseed non-GM total	7.37	7.23	-	23.93	7.18	7.03	7.17	7.21	7.07
Quantity demanded (Mtons)									
Oil for human cons.	2.80	2.75	2.97	2.54	2.73	2.67	2.72	2.74	2.69
Oil for industrial cons.	1.99	1.99	2.04	1.82	2.01	2.00	2.01	1.94	1.94
Meal GM	10.98	15.46	-	-	11.01	15.36	11.01	10.90	15.27
Meal non-GM	4.57	-	15.89	14.84	4.45	-	4.44	4.47	-

Note: S.1a = baseline, S.1 = mandatory oil and voluntary meal labeling; S.2 = mandatory oil labeling only, S.3 = NPBT regulated as non-GM, S.4 = NPBT banned.

Table 6. Welfare Effects of NPBT Regulation in Comparison to Baseline (S.1a) in Million Euros

	A. Labeling effects w/o segregation and coexistence costs				B. With 10% oil segregation cost		C. With 20% meal segregation cost	D. With 5% coexistence cost	
	S.1a	S.2a	S.3a	S.4a	S.1b	S.2b	S.1c	S.1d	S.2d
Change in Producer Surplus									
ΔPS total	**0**	**-200**	**-542**	**1,608**	**-206**	**-406**	**-216**	**420**	**213**
…for GM farmers	0	-105			-94	-200	-98	370	260
…of non-GM farmers	0	-95			-112	-207	-118	50	-47
Consumer Surplus Change									
ΔCS total	**0**	**-25**	**883**	**-2,413**	**-33**	**-54**	**-34**	**-682**	**-697**
…for human oil cons.	0	-115	370	-540	-155	-270	-162	-127	-240
…for industrial oil cons.	0	-18	124	-513	42	25	44	-162	-176
…for biodiesel oil cons.	0	-44	292	-1,274	99	60	103	-389	-424
…for overall meal	0	164	70	6	-6	157	-6	-10	150
Total Welfare Change									
ΔW Total	**0**	**-212**	**315**	**-714**	**-226**	**-435**	**-232**	**-305**	**-477**

Note: S.1a = baseline, S.1 = mandatory oil and voluntary meal labeling; S.2 = mandatory oil labeling only, S.3 = NPBT regulated as non-GM, S.4 = NPBT banned, PS = producer surplus, CS = consumer surplus, W = welfare.

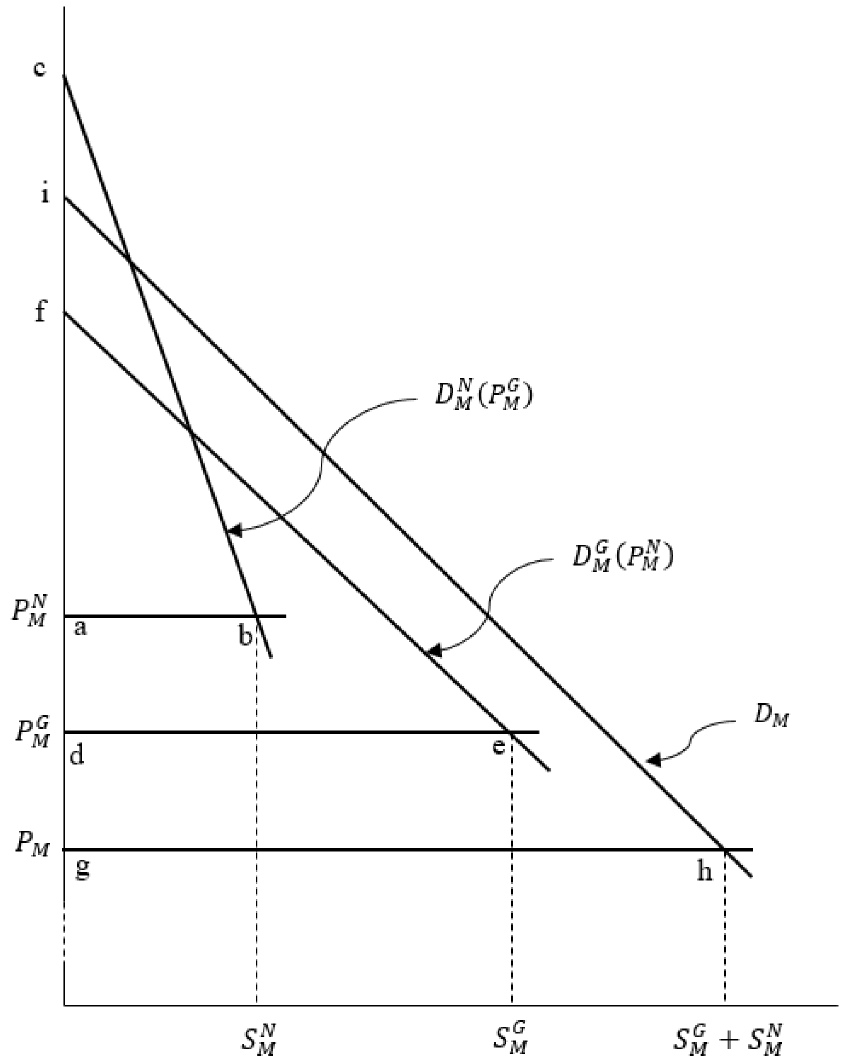

Figure 1. Vertically differentiated GM and non-GM demand and pooled demand for meal.

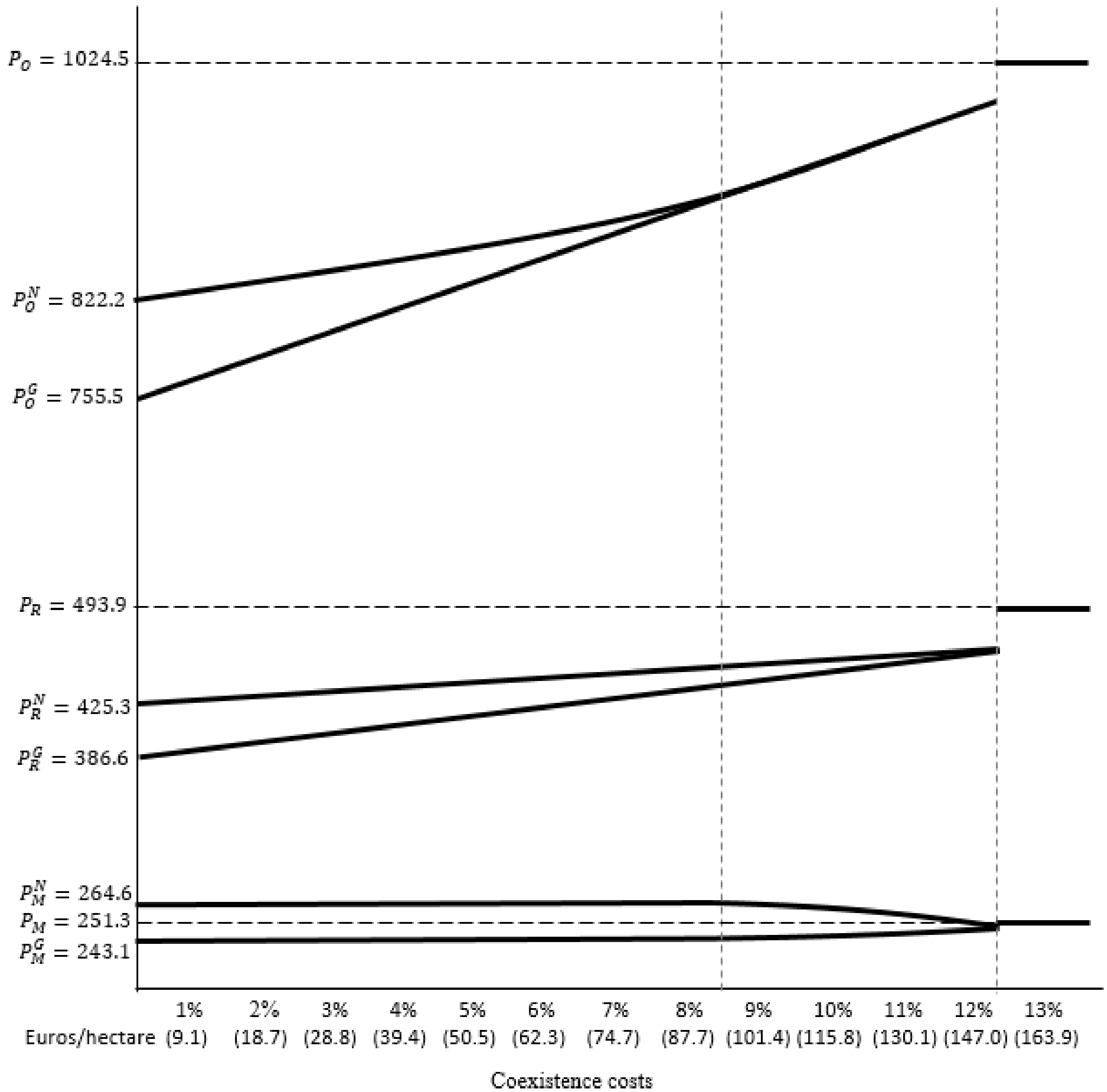

Figure 2. Effects of increasing coexistence costs (in percent of farmers' surplus and in euros per hectare) on GM and non-GM commodity prices

Appendix

Appendix A1: Equations System for the Baseline

For the supply of rapeseed, we assume a constant elasticity of supply form, $S_R^G\left(P_R^G\right)=A\left(P_R^G\right)^{\varepsilon_R^G}$ and $S_R^N\left(P_R^N\right)=C\left(P_R^N\right)^{\varepsilon_R^N}$. Applying the specific functional forms for the baseline, we obtain the following system of equations

$$P_R^G=\beta_O P_O^G+\beta_M P_M^G-c_R$$
$$P_R^N=\beta_O\left(P_O^N-s_O\right)+\beta_M\left(P_M^N-s_M\right)-c_R$$
$$\beta_O k(1-\theta)A\left(P_R^G\right)^{\varepsilon_R^G}=\frac{B}{\beta_B}+a_O^I-b_O^I P_O^G$$
$$\beta_O(Z-k)C\left(P_R^N\right)^{\varepsilon_R^N}=a_O^H-b_O^H P_O^N$$
$$(1-\theta)A\frac{\left(P_R^G\right)^{\varepsilon_R^G+1}}{\varepsilon_R^G+1}=C\frac{\left(P_R^N\right)^{\varepsilon_R^N+1}}{\varepsilon_R^N+1}$$
$$\beta_M k(1-\theta)A\left(P_R^G\right)^{\varepsilon_R^G}=a_M^G-b_M^G P_M^G+c_M P_M^N$$
$$\beta_M(Z-k)C\left(P_R^N\right)^{\varepsilon_R^N}=a_M^N-b_M^N P_M^N+c_M P_M^G$$

Given these equations and observed values of prices, quantities, and elasticicities, the unknown constants/variables in the baseline can be calibrated using the following equations

$$c_R^G=\beta_O P_O^G+\beta_M P_M^G-P_R^G;\;\; c_R^N=\beta_O\left(P_O^N-s_O\right)+\beta_M\left(P_M^N-s_M\right)-P_R^N$$
$$k=\frac{Z(\gamma+1)P_R^G\left(B/\beta_B+D_O^I\right)}{(\varepsilon+1)P_R^N D_O^H+(\gamma+1)P_R^G\left(\dfrac{B}{\beta_B}+D_O^I\right)}$$
$$A=\frac{B/\beta_B+D_O^I}{\beta_O k(1-\theta)\left(P_R^G\right)^{\varepsilon}},\;\; C=\frac{D_O^H}{\beta_O(Z-k)\left(P_R^N\right)^{\gamma}}$$
$$b_M^G=-\eta_M^{GG}\frac{\beta_M kS_R^G}{P_M^G};\;\; b_M^N=-\eta_M^{NN}\frac{\beta_M(Z-k)S_R^N}{P_M^N};\;\; c_M=\eta_M^{GN}\frac{\beta_M kS_R^G}{P_M^N}$$
$$a_M^G=\beta_M kS_R^G+b_M^G P_M^G-c_M P_M^N$$
$$a_M^N=\beta_M(Z-k)S_R^N+b_M^N P_M^N-c_M P_M^G$$

Appendix A2: Sensitivity Analysis

Table A.2. 10 and 90 Percent Range of Welfare Changes through a Sensitivity Analysis of Supply and Demand Elasticities

	A. Labeling effects w/o segregation and coexistence costs				B. With 10% oil segregation cost		C. With 20% meal seg. c.	D. With 5% coexistence cost	
	S.1a	S.2a	S.3a	S.4a	S.1b	S.2b	S.1c	S.1d	S.2d
Change in Producer Surplus									
ΔPS total	0	[-211,-185]	[-640,-441]	[1329,1905]	[-218,-194]	[-426,-381]	[-237,-203]	[398,443]	[189,243]
…for GM farmers	0	[-112,-97]			[-100,-97]	[-210,-186]	[-112,-99]	[351,390]	[243,281]
…of non-GM farm.	0	[-100,-88]			[-118,-106]	[-217,-194]	[-125,-106]	[45,56]	[-56,-35]
Consumer Surplus Change									
ΔCS total	0	[-31,3]	[754,948]	[-2648,-2027]	[-32,-8]	[-56,-6]	[-34,-9]	[-715,-663]	[-724,-662]
…for human oil c.	0	[-119,-109]	[342,399]	[-628,-458]	[-159,-151]	[-278,-262]	[-161,-153]	[-134,-121]	[-248,-230]
…for industrial oil	0	[-21,-14]	[105,144]	[-576,-454]	[39,44]	[20,31]	[40,45]	[-168,-156]	[-183,-169]
…for biodiesel oil	0	[-51,-33]	[246,339]	[-1440,-1123]	[93,104]	[48,74]	[94,106]	[-403,-376]	[-440,-407]
…for overall meal	0	[135,188]	[56,73]	[-6,10]	[-6,-5]	[128,181]	[-6,-5]	[-11,-9]	[122,-174]
Total Welfare Change									
ΔW Total	**0**	**[-222,-204]**	**[296,326]**	**[-747,-694]**	**[-226,-226]**	**[-444,-426]**	**[-232,-232]**	**[-272,-265]**	**[-487,-467]**

Note: S.1a = baseline, S.1 = mandatory oil and voluntary meal labeling; S.2 = mandatory oil labeling only, S.3 = NPBT regulated as non-GM, S.4 = NPBT banned, PS = producer surplus, CS = consumer surplus, W = welfare.

Table A.3. Welfare Changes with Elastic Oil Demand (η_O^H = -3.0)

	A. Labeling effects w/o segregation and coexistence costs				B. With 10% oil segregation cost		C. With 20% meal segregation cost	D. With 5% coexistence cost	
	S.1a	S.2a	S.3a	S.4a	S.1b	S.2b	S.1c	S.1d	S.2d
Change in Producer Surplus									
ΔPS total	**0**	**-433**	**226**	**394**	**-504**	**-951**	**-529**	**169**	**-282**
…for GM farmers	0	-212			-231	-454	-243	255	30
…of non-GM farmers	0	-221			-273	-497	-286	-86	-313
Consumer Surplus Change									
ΔCS total	**0**	**223**	**116**	**-1,051**	**284**	**531**	**298**	**-39**	**-75**
…for human oil cons.	0	-36	145	-157	-48	-86	-50		
…for industrial oil cons.	0	31	-38	-254	103	143	108	-111	-71
…for biodiesel oil cons.	0	73	-90	-617	243	337	255	-266	-169
…for overall meal	0	156	98	-22	-14	136	-14	-17	133
Total Welfare Change									
ΔW Total	**0**	**-210**	**342**	**-657**	**-220**	**-421**	**-231**	**-264**	**-465**

Note: S.1a = baseline, S.1 = mandatory oil and voluntary meal labeling; S.2 = mandatory oil labeling only, S.3 = NPBT regulated as non-GM, S.4 = NPBT banned, PS = producer surplus, CS = consumer surplus, W = welfare.